

A Low-Cost Miniaturized Laser Heterodyne Radiometer (Mini-LHR) for Near-IR measurements of CO₂ and CH₄ in the atmospheric column

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Abstract: The miniaturized laser heterodyne radiometer (mini-LHR) is a ground-based passive variation of a laser heterodyne radiometer that uses sunlight to measure absorption of CO₂ and CH₄ in the infrared. Sunlight is collected using collimation optics mounted to an AERONET sun tracker, modulated with a fiber switch and mixed with infrared laser light in a fast photoreceiver. The amplitude of the resultant RF (radio frequency) beat signal correlates with the concentration of the gas in the atmospheric column.

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1. Introduction

Laser heterodyne radiometry is a technique based on the radio receiver that has been in use since the 1970s [1-4] for measuring trace gases in the atmosphere. We have developed a passive miniaturized version of this technique using low-cost distributive feedback (DFB) lasers to measure the concentration of CO₂ and CH₄ in the atmosphere by measuring their absorption of sunlight in the infrared [5-8]. In contrast to a radio receiver where signals are collected with an antenna, in the mini-LHR, signals are sunlight collected with a collimator connected to a sun tracker. Both in a radio receiver and the mini-LHR, a local oscillator is mixed with the weaker incoming signal. In the mini-LHR, this local oscillator is a laser and the mixer is a fast photoreceiver. The resulting beat signal is proportional to the concentration of the trace gas in the atmosphere. The mini-LHR collects data by scanning the laser across the wavelength of the absorption feature in the infrared, and monitoring the output in the radio frequency (RF).

The mini-LHR has been designed to use the sun tracker from AERONET (a global network of more than 500 sensors that measure aerosol optical depth) [9]. The benefit of this partnership is that the mini-LHR could be deployed into this global network and provide validation for satellite missions as well as a long-term stand alone data product.

2. Instrument description

The mini-LHR (Miniaturized Laser Heterodyne Radiometer) design is shown in Figure 1. From left to right, sunlight that has undergone absorption by CO₂ and CH₄ in the infrared is collected with collimation optics connected to the sun tracker of an AERONET sun photometer. This offers a simultaneous measurement of aerosols, known to be important modulators in regional carbon cycles. Collected sunlight is launched into a single mode optical fiber and modulated with a fiber switch. Sunlight is superimposed with infrared laser light (from a

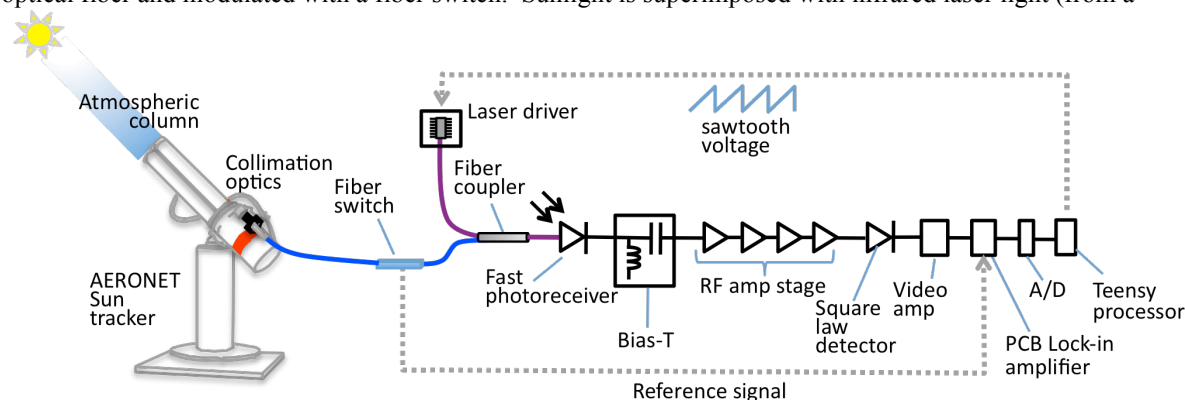


Figure 1. A schematic of the current version of the Mini-LHR. The partnership with AERONET provides a simultaneous measurement of aerosol optical depth as well as a path to a global network of these instruments.

distributive feedback (DFB) laser) in a single mode fiber coupler, and then mixed in a fast photoreceiver (an InGaAs detector) to produce an RF beat signal. A bias tee with a 50 ohm resistor separates RF and DC outputs. The RF signal passes through a gain stage to amplify and set the bandwidth of the measurement, and is then detected with a square-law detector. The signal is measured with a printed circuit board (PCB) lock-in amplifier as the laser scans across an absorption feature. A teensy processor controls both laser operation and data collection.

3. Results and Analysis

To produce a column CH_4 or CO_2 mole fraction from a scan, the retrieval algorithm first simulates the measurement using a high spectral resolution radiative transfer model and then scales this to the solar zenith angle at the time of the measurement. The scaled transmittance is corrected for instrument broadening, and then the instrument scan is fit to the simulated measurement to extract the mole fraction. Column data is typically collected at ~ 3 minute intervals throughout the day during sunlight hours when clouds are not present. Typical single scans of CO_2 and CH_4 in the atmospheric column are shown in Figure 2. To reach sensitivity requirements (1 ppm for CO_2 and 20 ppb for CH_4), multiple scans (typically 20) are individually analyzed with the algorithm and then averaged.

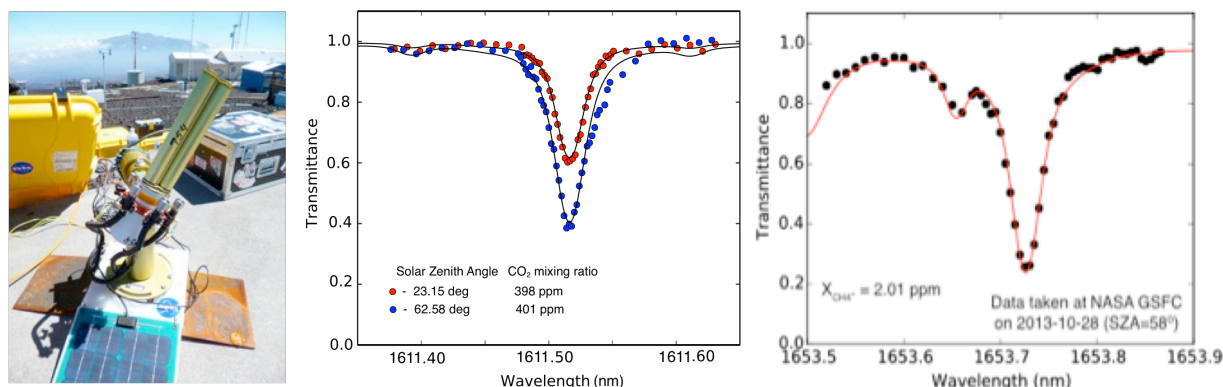


Figure 2. From left to right: the mini-LHR collects column CO_2 and CH_4 data at Mauna Loa Observatory in Hawaii, typical single data scans of carbon dioxide at two different solar zenith angles (published in Applied Physics B, 2015), a single column methane scan measured at GSFC.

4. Conclusion and Future Directions

We have presented the design of a low-cost miniaturized laser heterodyne radiometer that measures CO_2 and CH_4 in the atmospheric column and uses commercially available telecommunications components. The current analysis indicates that sensitivities of 1 ppm and 20 ppb can be achieved for CO_2 and CH_4 respectively by averaging multiple scans. The mini-LHR has been field tested in a range of environments including sites in Maryland, California, Wisconsin, Hawaii, and Alaska. While work is still needed to ruggedize the instrument for long term use, steps that follow would include licensing the mini-LHR to a company for manufacturing and distribution so that it can be deployed globally into established AERONET sites.

5. References

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